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THE EFFECT OF THE MENSTRUAL CYCLE
ON PHYSICAL WORK CAPACITY 170

BY

© NANCY C. GRUBER

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effect of the Menstrual Cycle on Physical Work Capacity 170," submitted by Nancy Christine Gruber in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of this study was to investigate differences in PWC_{170} measured in KPM/min. and KPM/min./haemoglobin concentration. Also investigated was the relationship between haemoglobin concentration and physical work capacity values.

Twenty-five female students from the first, second, and third year education and recreation programs at the University of Alberta participated in the study. All subjects were free of any acknowledged menstrual disorders, had regular cycles and were not taking oral contraceptives. Each subject was measured for weight, haemoglobin concentration, and PWC_{170} by means of the Sjostrand Test on day 2, 9, 17, and 26 of her menstrual cycle, corresponding to four phases of the cycle -- flow, postflow, midflow, and preflow phases respectively.

No significant differences occurred at the .05 level of significance for PWC_{170} or for PWC_{170}/haemoglobin concentration during the four different phases of the menstrual cycle. Also, no significant relationship was found between haemoglobin concentration and physical work capacity values during any phase of the cycle.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The ability to perform hard physical work is related to the maximal capacity of the cardiovascular-respiratory system to take up, transport, and give off oxygen to the working tissue, and for these tissues to use the oxygen (16). Many factors are involved in this process -- one of them being the total amount of haemoglobin in the body.

Haemoglobin is the oxygen-carrying component of the red blood cells. In the normal female, the average haemoglobin when fully saturated combines with 1.34 ml. oxygen, so that the haemoglobin concentration is an index of the oxygen-carrying power of the blood. A normal woman carries 18 gm. oxygen per 100 ml. blood (26, 35).

Kjellberg *et al*. showed a +0.90 correlation between the amont of haemoglobin and pulse rate during work of 600 KPM/min. or the work at which the pulse reached a level of about 170 beats/minute. Astrand (4) found a high correlation (+0.97) between the total amount of haemoglobin in the body at rest and maximal oxygen uptake.

Sjostrand (51) reported that blood volume and haemoglobin volume in any individual were fairly constant. Although both volumes appeared to increase slightly in March and April and to decrease during August and September, haemoglobin concentration remained constant.

Studies indicated that during menstruation the mean blood loss was between 35-50 ml. blood with a total range of 6-180 ml. blood (8, 30, 31). Iron, essential for haemoglobin synthesis, was not normally

lost from the body with the exception of iron in the menstrual blood of women. A mean of 13 mg. iron was reported lost during menstruation (26, 33).

Very little research has been done to investigate the effects of menstruation and subsequent blood loss, iron loss, and decreased haemoglobin concentration on physical work capacity or maximal oxygen uptake. With the increasing participation of women in competitive sport, the effects of the menstrual cycle on athletic performance need to be fully understood.

The Problem

The purpose of this study was to investigate differences in physical work capacity as determined by the Sjostrand Test during the four phases of the menstrual cycle.

Subsidiary Problems

The study also investigated:

1. Differences in PWC_{170}/haemoglobin concentration during the four phases of the menstrual cycle.
2. The relationship between haemoglobin concentration and physical work capacity values determined from submaximal efforts on the Sjostrand Test.

Hypotheses

The following null hypotheses were tested at the 0.05 level of significance.

1. There is no difference in PWC_{170} during the four phases of the menstrual cycle.
2. There is no difference in PWC_{170}/haemoglobin concentration

during the four phases of the menstrual cycle.

3. No relationship exists between haemoglobin concentration and physical work capacity values.

The alternate hypotheses asserted that there are significant differences in PWC_{170} and PWC_{170}/haemoglobin concentration during the four phases of the menstrual cycle, and that a significant relationship exists between haemoglobin concentration and physical work capacity values.

Justification for the Study

Although many of the physiological effects of the menstrual cycle are known, very few studies have related these normal cyclic changes to their effects on women's athletic performance. Several European investigators (19, 23) have suggested the use of drugs to bring on or to delay the onset of menstruation, especially during athletic competition. However, little has been done on the North American continent to establish if any particular phase of the menstrual cycle alters the physical work capacity or athletic performance in women.

Limitations

1. The temperature and humidity in the laboratory were not controlled.

Delimitations

1. The study was limited to twenty-five female university students from the first, second, and third year physical education and recreation programs. Subjects were screened to accept for testing only those who experienced little or no dysmenorrhea or premenstrual tension and had regular

cycles approximately 28 days in length. No subjects were taking oral contraceptives.

2. The menstrual cycle was divided into four stages and testing was carried out on the mid-day of each of these stages.

Definition of Terms

1. Physical Work Capacity 170 (PWC_{170}) -- the amount of work (measured in kilipond meters per minute) that an individual is capable of performing at a steady state heart rate of 170 beats per minute. The principle of PWC_{170} is based on the linear relationship that exists between steady state heart frequencies and oxygen uptake. By extrapolating or interpolating along this relationship, one can determine a value for PWC_{170}.
2. Submaximal Test -- a test which the subject can perform without reaching exhaustion or maximal oxygen uptake.
3. Work Load -- the calibrated force of a friction belt which must be overcome by a subject who pedals at a prescribed rate. The work done is a product of the cycling rate, the distance cycled as determined by the wheel circumference, and the belt resistance.
4. Kilipond Meter -- the force acting on the mass of one kilogram at the normal acceleration of gravity.
5. Haemoglobin Concentration -- the amount of haemoglobin (measured by weight in grams) present in every 100 milliliters of blood.

5. Phases of the Menstrual Cycle

Test days during the four phases of the menstrual are illustrated in Table I and Figure I.

i) Flow Phase -- the days of actual blood flow.

ii) Postflow Phase -- the nine days immediately following the last day of blood flow.

iii) Midflow Phase -- the eight days immediately preceding the preflow phase.

iv) Preflow Phase -- the seven days immediately preceding the onset of menstruation.

TABLE I

TEST DAYS AND LENGTH OF THE FOUR MENSTRUAL PHASES

Phase	Phase Length (Days)	Test Day
Flow	4	2nd day of flow
Postflow	9	5th day after flow ends
Midflow	8	12th day prior to flow
Preflow	7	3rd day prior to flow

NOTE: Because of the difficulty in accurately predicting the onset of menstruation , an error margin of one day immediately prior to and following the test day is allowed during the postflow, midflow, and preflow phases.

If the menstrual cycle is not 28 days in length, the postflow phase is adjusted accordingly.

FIGURE I

THE FOUR PHASES AND TEST DAYS OF ONE COMPLETE MENSTRUAL CYCLE

Flow Postflow Midflow Preflow

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

Test days underlined.

Arrows indicate error margin allowed for test day.

CHAPTER II

REVIEW OF THE LITERATURE

Many physiologists consider maximal oxygen uptake to be the best single measure of an individual's capacity to perform prolonged physical work. Although many tests of maximal oxygen consumption and work capacity have been devised, this study is limited to the use of the Sjostrand Physical Work Capacity 170 Test. Investigators (3, 6) feel that the direct determination of aerobic capacity is preferred over indirect methods. However, the time and equipment necessary to make this evaluation are disadvantages when testing large samples or when repeatedly testing the same subjects. Also, it is especially difficult to motivate females to work to exhaustion four times, as would be the case in this study.

In view of these reasons, a submaximal test, the Sjostrand Physical Work Capacity 170 Test, was chosen.

Sjostrand Physical Work Capacity 170 Test

Few studies have tested the physical work capacity of women. Most of the studies that did use the Sjostrand PWC_{170} Test on females were normative studies on the general population so little information is available concerning the work capacity of female ahtletes.

Fedoruk (25) tested 24 females from the first year physical education professional program at the University of Alberta on two modified Sjostrand PWC_{170} Tests. He found the mean scores of the subjects to be 769 KPM/min. or 12 KPM/kg./min. This score is superior to that of 515 KPM found for Winnipeg nurses; however, it was lower than

the 840 and 835 KPM reported for Stockholm nurses and medical students, respectively (14). The Canadian Association for Health, Physical Education and Recreation (34) tested the physical work capacity of Canadian children. They report PWC_{170} values of 476 KPM/min. or 8.51 KPM/kg./min. for 17-year old female students randomly selected from the school population in Canada.

Bengtsson (9) compared the physical work capacity of 38 females aged 15-40 with that of males in the same age group and with children. The 15-20-year old girls had a mean PWC_{170} value of 770 KPM/min. while the 21-40-year old women had a mean value of 823 KPM/min.

Total Volume and Concentration of Haemoglobin

Sjostrand (50) studied 92 females between the ages of 17 and 70. He reported an average of 555 $\pm$ 11 gm. of total haemoglobin for the women, about 30% less than the male average. Verghese et al. (58) randomly selected 264 American female college freshmen for haemoglobin estimations. The mean was 12.4 gm.% haemoglobin concentration with a range of 7.6 to 16 gm.%. They suggested that if one accepted 12 gm.% as the lower limit, then 52.7% of the females they studied were anaemic. Ganong (26) reported an average normal haemoglobin content of blood of 14 gm./100 ml. in women.

Kjellberg et al. (36, 37) compared normal males and females with ahtletically trained men and women. They found that the amount of haemoglobin and the blood volume varied with the degree of physical training, but in all cases there was a clear correlation between haemoglobin and pulse rate during rest. They also found a high correlation (+0.90) between the amount of haemoglobin and the pulse rate during work of 600 KPM/min. or the work at which the pulse reached a level of

about 170 beats/minute (38).

Astrand (4) found that blood volume and total haemoglobin volume were directly correlated (+0.97) with maximal oxygen uptake during short periods of physical work. Differences in maximal oxygen uptake values between adults and children and between males and females corresponded to differences in their total haemoglobin values.

Haemoglobin Concentration and Athletic Performance

In a study on 46 males aged 14-20 years, Cullumbine (13) measured their haemoglobin concentrations and had the subjects perform tests of moderate exercise, severe exercise, prolonged moderate exercise, strength, and speed. He found a significant correlation (+0.44) between haemoglobin concentration and prolonged moderate exercise, speed, and strength. Cullumbine suggested that with short moderate exercise there was no significant correlation because the large reserve of the oxygen-carrying power of the blood was not strained. Also, with short severe exercise the subject became exhausted too fast to notice any change. The oxygen debt was too large to be influenced significantly by small changes in the haemoglobin level.

Balke *et al*. (7) removed 500 cc. blood from fourteen male subjects and tested their physical work capacity one hour later, two to three days later, and eight to ten days later. The results indicated that PWC values had dropped significantly from normal values an hour after giving blood and were still low two to three days later. The authors suggested that the decrease in performance may be due to the drop in haemoglobin concentration as the fluid lost in venesection is replaced much more rapidly than corpuscular elements.

Spealman *et al*. (53) reported similar findings. The removal

of 500 cc. blood resulted in an immediate and marked decrease in the subjects' ability to carry out physical activities in the heat. Several days elapsed before the control level of performance was attained again. A similar but less severe decrease in performance occurred after 200 cc. blood were removed.

Systemic Changes Due to the Menstrual Cycle

During menstruation, the blood loss in one series of normal women varied between 6 and 180 ml., the average loss being 50 ml. (8). A study by Hallberg et al. (31) showed a mean menstrual blood loss of 34 ml. in 137 Hungarian factory workers. However, Sjostrand (51) felt that any changes in blood volume could not be explained by blood loss due to menstruation since such loss was altogether too small. Studies by Elwood et al. (22), and Hallberg et al. (33) reported a mean iron loss during menstruation of 12-13 mg. Elwood (22) found that 14% of the variation in haemoglobin level was dependent on menstrual iron loss. Ganong (26) states that iron absorption is carefully regulated, and this is important because, except for the iron in the menstrual blood of women, little if any is normally lost from the body.

Garlick (27) compared the heart rate, blood pressure, and blood constituents of 18 young women measured during rest and after exercise on the first day of menstruation and again on the fourteenth day of the menstrual cycle. He reported significant differences in heart rate, blood pressure, haemoglobin concentration, and red blood cell count between day one and day fourteen of the cycle. However, these cyclic changes were noticeable only before exercise and were later masked by exercise response.

Dintenfass (17) tested the effects of the menstrual cycle on

blood viscosity in nine women. He reported a peak in blood viscosity during the fourth week, a rapid decrease during menstruation, followed by a levelling off and steady state until the third week. However, the decrease in viscosity was not due to an increase in haematocrit, instead it was the degree of aggregation of the red blood cells, and thus the structural-viscosity component of blood viscosity varied with the menstrual cycle. This was probably due to hormonal balance.

Elwood *et al*. (21) reported mean haemoglobin concentrations fluctuating during the menstrual cycle.

Several studies (2, 42, 52, 56) indicated that blood pressure increased a day or so before flow began. Pulse rate dropped during menstruation but accelerated at mid-cycle and during the luteal phase of the cycle. A recent study by Madge Phillips (46) tested the pulse rate and blood pressure of 24 female college students during four phases of the menstrual cycle. She reported that the cycle had no effect on pulse rate or blood pressure before or after exercise consisting of a one-minute step test. A pilot study done by Phillips (45) indicated that test results for one menstrual cycle were comparable to those for two cycles. Also, testing on a specific day of each phase of the cycle -- i.e. day 2, 8, 17, and 26 -- was comparable to testing on each day.

Anna Southam *et al*. (52) wrote an extensive review presenting systemic changes which have been observed during the menstrual cycle. They reported alterations in the respiration rate characterized by changes in the alveolar and arterial carbin dioxide tensions. The lowest respiration rate was just before the flow; it increased after the flow and was maintained until the luteal phase when it again decreased. A slight gain in weight during the premenstrual phase was

attributed to water, sodium, and chloride retention. There was increased blood destruction during the premenstrual phase but erythrocyte and haemoglobin concentrations did not vary appreciably during the cycle.

Chesley et al. (12) took salivary sodium and potassium measurements and weight measurements on 16 women through two menstrual cycles. They reported an average weight gain of ¼ pound 10-9 days before menstruation. Salivary sodium concentration, which may reflect the physiological activity of salt-retaining hormones, didn't vary significantly during the cycle.

The Menstrual Cycle and Athletic Performance

There appears to be controversy in the literature as to the effect of the menstrual cycle on reaction time. Pierson and Lockhurt (47) found no significant changes in reaction time and movement time during the cycle. They have suggested that the lessened efficiency observed during the premenstrual and menstrual phases may be due to a lack of concentration because of discomfort and distractions peculiar to this time. Loucks and Thompson (40) and Genasci (28) studied 20 and 24 females respectively. Both reported that menstruation had no effect on total body reaction time. However, a study by Campbell (11) showed that on seven tests of physical fitness, a group of 13 female athletes was found to have its best performance in the intermenstrual phase of the cycle. The poorest performance occurred during the menstrual period. Total body reaction time was the best single indicator.

Doring (19) assessed the muscle power coordination quotient of athletic effort in different phases of the menstrual cycle. He also investigated the relevant psychological factors associated with menstruation. The results of his study showed a reduction in athletic perfor-

mance during the menstrual flow and an even greater reduction during the premenstrual phase. The latter could be ascribed to the symptoms associated with the premenstrual syndrome. Doring felt the best time in the cycle for athletic performance was the immediated postmenstrual phase, when the performance of individual muscles and neuromuscular coordination were at their maximum efficiency. When menstruation coincided with an athletic event, Doring recommended postponing the period with drugs.

In a survey of sportswomen at the Tokyo Olympics, Zaharieva (60) found that when competing while menstruating, there was no difference in performance in 36.9% of the women, a variation in performance in 27.7%, and a poorer performance in 17%. He reported that the feeling of fitness among athletes was important and was found to change with menstruation -- 46% felt no change but 32% felt weaker. Also of importance was wheter athletes felt they could reach their peak form in competition while menstruating. Swimmers, especially, lost their self-confidence while volleyballers did not. In spite of feeling self-confident, many did not produce their best results.

Erdelyi (23) reported similar results from his survey of 729 Hungarian athletes. He found their best performance to be in the postmenstrual phase, followed by the mid-cycle phase. The poorest performance occurred during the premenstrual phase and the first two days of menstruation. According to Erdelyi, the greatest changes were seen in tennis and rowing (stamina sports) while very little fluctuation in performance was noticed in track sprinters. He proposed the use of drugs to change the menstrual cycle if an important competition falls on the same day as menstruation.

Two studies by Scott et al. (48) and Moore et al. (46) reported no significant fluctuations in physical efficiency of muscular strength sufficient to interfere with activities. Although both saw individual variations, these were often masked by daily fluctuations which could be accounted for by factors other than menstruation.

Blackshaw (10) tested seven girls, aged 12 to 18 years who were members of the Vancouver Amateur Swim Club. Each girl swam 100 meters of her specialty stroke on four occasions corresponding to four different phases of the menstrual cycle. Testing was conducted over two complete cycles. Blackshaw reported that menstruation adversely affected the performance of the swimmers and swimming times were significantly slower in the preflow and flow phases of the cycle.

In a study by Doolittle et al. (18) sixteen college women performed four exercise tests at four selected times during their menstrual cycle. The tests were a 12-minute run-walk, maximum oxygen consumption, a 600 yard run-walk, and a 1.5 mile run-walk. Both the order of the tests and the starting phase in the cycle were counterbalanced among the subjects. The results indicated that performance did not differ significantly throughout the menstrual cycle.

According to the authors of the Amateur Athletic Union Report (1), 85% of women can compete during menstruation and perform to their usual standard. The remainder may have increased pain or a profuse flow. In spite of these findings, however, it is suggested that for emotional reasons girls should refrain from competition during menstruation.

CHAPTER III

METHODS AND PROCEDURES

Sample

The sample consisted of twenty-five female university volunteers from the first, second, and third year physical education and recreation professional programs at the University of Alberta.

Selection of Subjects

1. Subjects were required to have regular periods corresponding as closely as possible to a 28 day cycle. Volunteers were asked to keep a calendar record of their menstrual cycle for two months prior to testing.
2. Subjects were required to have a score of 32 or less on a screening test for dysmenorrhea and premenstrual tension. This test was designed for a study done by Dr. R. Campbell (11).

Standardization of Procedures

To standardize the testing procedures as much as possible, subjects were requested to refrain from eating, smoking, and any strenuous exercise one and one-half hours prior to testing. Test schedules were arranged so all subjects were tested at the same relative time of the day.

Tests were conducted over a period of six weeks with all subjects being tested during one complete menstrual cycle. Subjects were in various phases of the cycle when testing began. The tests were administered as closely as could be determined on the mid-day of each

stage of the cycle. Subjects were asked to report immediately the onset of menstrual flow.

Testing Procedure

As each subject reported to the lab, she was weighed in stocking feet and a small blood sample was drawn to be analyzed for haemoglobin concentration. Following this, the subject completed the Sjostrand Test for PWC_{170}.

Heart Rate

The heart rate was recorded on a Sanborn electrocardiograph.

Modified Sjostrand PWC_{170}

This test was originally described by Sjostrand (49). Since then it has been modified to a twelve minute ride on the bicycle ergometer. It was administered as follows:

The seat height was adjusted for each subject, the subject was connected to the electrodes, and the metranome was set for 60 complete pedal revolutions per minute. Each subject pedalled for three, four-minute workrates, beginning at a 300 KPM workload. The second and third workloads were adjusted according to heart rate responses recorded at the third and seventh minute of the test. The workloads were adjusted to elicit steady state heart rates within the ranges 115-130, 130-155, and 160-180 beats per minute for each of the three workloads respectively. The heart rates were plotted against workloads and a workload necessary to produce a steady state heart rate of 170 beats per minute was determined. This value was the subject's score for PWC_{170}.

Haemoglobin Concentration

The method for determining haemoglobin concentration was first outlined by Drabkin (20). Haemoglobin is converted to cyanmethemoglobin by the addition of potassium ferricyanide and sodium cyanide. The density of the colour produced is directly proportional to the amount of haemoglobin present. The cyanmethemoglobin method is the standard method used by most laboratories. It was administered as follows:

The subject's finger was pricked by a blood lancet. The first drop of blood was wiped away. Twenty cmm. (0.02 ml.) of blood were diluted with 5 ml. Drabkin's solution. After at least 10 minutes, the density of the solution was measured photometrically at 540 millimicrons, using a clear blank. The reading from the Klett-Summerson Photoelectric Colorimeter was multiplied by a factor of 0.071 to obtain the concentration of grams haemoglobin/100 ml. blood. Two samples were taken from each girl at each test session and the average of these two samples was taken as the final value for haemoglobin concentration.

Statistical Procedures

Five one-way analyses of variance with repeated measures were used to test the significance of the difference between means for weight, haemoglobin concentration, PWC_{170}, PWC_{170}/kg. body weight, and PWC_{170} /haemoglobin concentration during the four phases of the menstrual cycle. A Fortran IV ANOV15 program was obtained from the Department of Educational Research. The program was computed on the IBM 360/67 computer at the University of Alberta Computing Science Department.

The relationships between haemoglobin concentration and PWC_{170} at four phases of the menstrual cycle were determined using a Pearson product-moment correlation coefficient.

The 0.05 level of significance was accepted for all tests.

CHAPTER IV

RESULTS AND DISCUSSION

Characteristics of the Subjects

Twenty-five female students from the first, second, and third year professional physical education and recreation programs at the University of Alberta participated in the study. Table II presents the mean, standard deviation, and range of the subjects' age, height, and weight.

TABLE II

CHARACTERISTICS OF TEST SUBJECTS

	Mean	Standard Deviation	Range
Age (yr.)	19.68	1.49	18 - 24
Height (cm.)	160.92	6.05	151.13 - 172.72
Weight (kg.)	59.68	7.50	48.54 - 84.60

The characteristics of these subjects are similar to the characteristics of the subjects in studies by Campbell (11), Fedoruk (25), Garlick and Bernauer (27), MacKinnon (42), and Phillips (46). In these studies the mean age varied between 19 and 20 years and the mean weight varied between 59 and 62 kilograms.

Results of Tests

Each subject was tested on the mid-day of each of four phases

TABLE III

MEAN SCORES OF TEST RESULTS DURING FOUR PHASES OF THE MENSTRUAL CYCLE

	FLOW PHASE		POSTFLOW PHASE		MIDFLOW PHASE		PREFLOW PHASE		TOTAL OF 4 PHASES	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Weight (kg.)	59.87	7.80	59.52	7.66	59.60	7.42	59.73	7.74	59.68	7.80
Haemoglobin Concentration (gm./100 ml. blood)	13.54	0.56	13.77	0.61	13.62	0.65	13.73	0.51	13.67	0.59
PWC_{170} (KPM/min.)	774.80	138.65	755.84	145.68	792.80	147.45	740.24	120.97	765.92	137.21
PWC_{170}/kg. body weight	12.93	1.71	12.70	1.91	13.30	1.94	12.40	1.52	12.83	1.77
PWC_{170}/Hb concentration	57.22	9.99	56.57	14.61	58.29	10.72	53.97	8.96	56.51	11.16

of the menstrual cycle. At this time weight, haemoglobin concentration, and PWC_{170} from the Sjostrand Physical Work Capacity Test were measured. The means of these tests are illustrated in Table III.

Effect of Phases of the Menstrual Cycle

Five one-way analyses of variance with repeated measures were applied to determine if there were significant differences between mean weight, haemoglobin concentration, PWC_{170}, PWC_{170}/kg. body weight, and PWC_{170}/haemoglobin concentration during the four phases of the menstrual cycle. Results of the analyses of variance are presented in Tables IV, V, VI, VII, and VIII. The critical F-ratio at the 0.05 level of significance was 2.71.

There were no significant differences between mean scores during four phases of the cycle for any of the variables tested.

TABLE IV

RESULTS OF ANALYSIS OF VARIANCE:

WEIGHT DURING FOUR MENSTRUAL PHASES

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Groups	3	2.19	0.73	0.01
Error	96	5625.19	58.60	

Body Weight

From Tables III and IV it can be seen that the mean weight of the subjects did not vary appreciably between phases of the menstrual

cycle. In all phases weight remained constant at 59 kg. These results agree with the findings of Blackshaw (10) who found that the weight of seven female swimmers varied only slightly over two menstrual cycles. Campbell (11) also reported no significant changes in weight during four phases of the cycle in his study of thirteen physically active students. Chesley and Hellman (12) found only slight and insignificant increases in weight premenstrually. Their studies on salivary sodium concentration, which is said to reflect the activity of salt retaining hormones, did not show any significant variation during the menstrual cycle.

TABLE V

RESULTS OF ANALYSIS OF VARIANCE:

HAEMOGLOBIN CONCENTRATION DURING FOUR MENSTRUAL PHASES

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Groups	3	0.93	0.31	0.89
Error	96	33.45	0.35	

Haemoglobin Concentration

Tables III and V indicate that haemoglobin concentration did not vary significantly throughout the menstrual cycle. The mean value of 13.67 $\pm$ .59 gm./100 ml. blood corresponds quite closely with Ganong's (26) reported value of 14 gm./100 ml. blood. Verghese *et al*. (58) found a mean haemoglobin concentration of 12.4 $\pm$ 1.1 gm./100 ml. blood in their study of 264 randomly selected female college freshmen. Kjellberg

et al. (36) reported that trained subjects had slightly higher haemoglobin concentrations and blood volumes than untrained subjects and that the amount of haemoglobin and blood volume varied with the degree of physical training. The subjects participating in this study were all physical education students and one can assume that they were more active and in better physical condition than the normal population. This might explain the higher mean value of haemoglobin concentration when compared with that obtained by Verghese (58) who selected subjects randomly from the first year university population.

In this study haemoglobin concentration did not fluctuate significantly throughout the menstraul cycle. This is contrary to the results of Garlick and Bernauer (27) who tested 18 undergraduates on the Astrand-Rhyming bicycle ergometer test and compared heart rate, blood pressure, and blood constituents before and after exercise on the first day of menstruation to values obtained on day fourteen of the cycle. They found a significant increase in haemoglobin concentrations on day fourteen during rest. These changes were later masked by the response to exercise. Anna Southam et al. (52) report an increase in blood destruction during the premenstrual phase. Also, estrogen administered to humans produces an initial increase in the red blood cell count, haemoglobin concentration, and haematocrit. During a normal twenty-eight day menstrual cycle estrogen levels reach a peak on day fourteen and again around day twenty-one (26). Garlick (27) tested on days one and fourteen of the cycle, the latter test day being a time when the estrogen level in the body is at its peak. In this study, testing occurred on days two, nine, seventeen, and twenty-six of the cycle, when the estrogen level is lower.

Hallberg *et al.* (31) tested 137 female factory workers and found that haemoglobin concentration was reduced during menstruation only in a few subjects with a blood loss greater than 100 ml. each menstrual period. The mean menstrual blood loss reported by Hallberg (31), Barker (8), and Guyton (30) was between 35-50 ml. The mean iron loss during menstruation was between 12.2-13 mg. (22, 26). Hallberg *et al.* (32) calculated that with a normal daily iron intake and a haemoglobin concentration af at least 12 gm./100 ml. blood, the iron balance in the body will be maintained with menstrual blood losses up to 63 ml. Haemoglobin concentration, therefore, will not decrease because of insufficient iron for haemoglobin synthesis. In this study the lowest haemoglobin concentration measured was 11.86 gm./100 ml. blood. This occurred unaccountably during the midflow phase of one subject. All other concentration values were above 12 gm./100 ml. blood.

TABLE VI

RESULTS OF ANALYSIS OF VARIANCE:

PWC_{170} DURING FOUR MENSTRUAL PHASES

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Groups	3	39040.	13013.33	0.68
Error	96	1843696.	19205.16	

TABLE VII

RESULTS OF ANALYSIS OF VARIANCE:

PWC_{170}/KG. BODY WEIGHT DURING FOUR MENSTRUAL PHASES

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Groups	3	10.68	3.56	1.13
Error	96	303.30	3.16	

TABLE VIII

RESULTS OF ANALYSIS OF VARIANCE:

PWC_{170}/HB CONCENTRATION DURING FOUR MENSTRUAL PHASES

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Groups	3	254.13	84.71	0.67
Error	96	12200.	127.08	

Physical Work Capacity 170

Physical work capacity 170 varied between menstrual phases from 740 KPM/min. (12.40 KPM/kg./min.) to 792 KPM/min. (13.30 KPM/kg. /min.) with a mean of 765 KPM/min. (12.83 KPM/kg./min.). (See Table III.) This is in very close agreement with the results of Fedoruk (25) who tested 24 females from the Faculty of Physical Education, University of Alberta and found a mean PWC_{170} value of 769 KPM/min. or 12.97 KPM /kg./min.

Bengtsson (9) reported a mean PWC_{170} score of 770 KPM/min. for girls aged 15-20. However, most of the girls did not claim to be physically fit and did not engage in competitive or regular sport.

Cumming (15) presented a table comparing mean values of PWC_{170} of women 18-40 years of age from Winnipeg and from Stockholm. Winnipeg student nurses had a mean score of 515 KPM/min. while Stockholm nurses and female medical students had scores of 840 and 835 KPM/min. respectively. The European population is more accustomed to bicycle riding and may be in a better physical condition because of the popularity of the sport. This may account for some of the observed differences between the two populations.

The Canadian Association for Health, Physical Eductaion, and Recreation reported a PWC_{170} score of 476 KPM/min. and 8.51 KPM/kg./min. for 17-year old females selected randomly from the school population. One must remember that the girls in the CAHPER study were approximately two years younger than subjects in this study. Also, they represent a random selection from the school population, as compared to students in a physical education program. These facts may account for the rather substantial difference in PWC_{170} scores.

Although trends in performance can be seen with the lowest mean PWC_{170} score occurring in the midflow phase, none of these differences was statistically significant (see Tables III, VI, VII, VIII). Several investigators (42, 48, 56) reported that pulse rate accelerated and reached a peak during the midflow phase and was lowest during menstrual flow. Scott (48) took pulse rates of 100 women aged 16-41 while they performed a bench-stepping exercise. She concluded that although both physical efficiency and pulse rates varied, the menstrual cycle

brought about no significant cyclic rise and fall in the variables. Variations and fluctuations were due to factors other than the menstrual cycle. Madge Phillips (46) took the pulse rate and blood pressure of 24 women prior to and following a one-minute step test. She reported no significant differences in mean scores during four phases of the menstrual cycle.

Results of a study by Moore *et al.* (44) who tested the strength of 30 physically active university students, showed that muscular strength increased during the midflow and preflow phases of the cycle and decreased during menstrual flow. However, the depression in strength during flow was not sufficient to interfere with activities. Variations were often masked by daily fluctuations which could be accounted for by daily routines.

Results from Doolittle's study (18) on 16 college women indicated that performance on four tests -- 12-minute run-walk, maximum oxygen consumption, 600-yard run-walk, and 1.5-mile run-walk -- was not dependent upon the time in the female's menstrual cycle.

Many of the studies just noted involved tests measuring only pulse rate and blood pressure, usually within a laboratory setting. Many other physiological and psychological factors have a great influence on physical performance. Certainly none of the subjects experienced the mental and emotional pressures accompanying a rigid training schedule and athletic competition. Surveys and tests on Olympic calibre athletes indicate that performance in many events is affected by the menstrual cycle. Erdelyi (23) reported that of the 729 female Hungarian athletes he questioned, 83% felt their performance did not vary with menstruation, 5% actually felt they gave better performances, and 11% thought their

performance decreased during menstruation. Testing of the athletes indicated that 42% had no change in performance during menstrual flow, 30% had poorer performance, and 13% had better performance. Erdelyi found the best performance to occur during the postmenstrual phase, followed by the mid-cycle phase. The poorest performance was observed during the premenstrual phase and the first two days of the cycle. The greatest changes occurred in the stamina sports of tennis and rowing, while track sprinters experienced little fluctuation in performance.

Doring (19) found similar results in his study of female athletes. He attributed the poorer performances of the premenstrual and menstrual phases to the psychological depression occurring especially during the premenstruum. By investigating relevant psychological factors associated with menstruation, Doring found a deep point in depression three days before menstruation began. He believed that the optimum time of the cycle was in the immediate postmenstrual phase when the performance of individual muscles and neuromuscular coordination were at their maximum efficiency.

Zaharieva (60) studied 66 sportwomen at the Tokyo Olympics who were participating in track and field, swimming, gymnastics, and volleyball. He found that performance varied during menstruation in 27% of the women and actually declined in 17%. Menstruation also affected the feeling of fitness among the athletes as 32% said they felt weaker during this time. Swimmers lost their self-confidence while volleyballers did not although many did not give their best performance.

Coppen and Kessel (13) surveyed 465 women from the general population in an area in England. Results of the questionnaire indicated that 45% of women experienced moderate dysmenorrhea, which was maximal

on the first day of menstruation. Dysmenorrhea also showed a high correlation with menstrual irritability, depression, headaches, and the sensation of swelling. Psychological symptoms such as depression and tension were worst before menstruation began when swelling, especially of the breasts and abdomen, was also at its worst.

It can be seen that performance of some athletes is definitely affected by the menstrual cycle. Since performance is dependent upon many variables, both physiological and psychological, laboratory testing of several of these variables may not show fluctuations sufficient, by themselves, to alter athletic performance during competition. The Sjostrand Physical Work Capacity is dependent solely upon observation of the heart rate. Results from other investigators (46, 48, 56) indicate that resting heart rate does not alter throughout the cycle sufficiently to affect performance. Also, physiological responses to exercise may compensate for any slight changes in the resting heart rate. Therefore, although physical work capacity does not vary during the menstrual cycle, other influences such as premenstrual tension may affect some individuals and cause a variation in their performance throughout the menstrual cycle.

Relationship of Haemoglobin Concentration and Physical Work Capacity

Correlation coefficients between work capacity and haemoglobin concentrations during the four phases of the menstrual cycle are presented in Table IX. To be significantly different from zero at the 0.05 level of significance, the correlation coefficient must be of the magnitude of $\pm$ 0.34.

TABLE IX

CORRELATIONS OF HAEMOGLOBIN CONCENTRATION AND WORK CAPACITY

DURING FOUR PHASES OF THE MENSTRUAL CYCLE

	Physical Work Capacity 170			
	Flow Phase	Postflow Phase	Midflow Phase	Preflow Phase
Haemoglobin Concentration	+.02	+.06	+.21	+.05

None of the correlation coefficients presented here is significantly different from zero, indicating that there is no relationship between haemoglobin concentration and physical work capacity during any phase of the menstrual cycle.

Spealman _et_ _al_. (43) removed 500 cc. of blood from four subjects who then performed tests on a tilt table and on a bicycle ergometer. Performance testing was also done on the subjects after a 24-hour bed rest, and after exposure to the cold. Haemoglobin concentration in these last two situations was normal. The results indicated that performance was dependent on blood volume but there was no consistent relationship between performance and haemoglobin concentration.

Cullumbine (14) tested 200 girls and boys aged 10-20 to determine the effect of haemoglobin concentration on the ability to perform various types of physical exercise. Subjects were asked to perform tests involving moderate exercise (Harvard Step Test), severe exercise (Endurance Step Test), prolonged moderate exercise (Harvard Step Test done to exhaustion), speed, and strength. Although a positive correlation was found between haemoglobin concentration and tests of

moderate or severe exercise. Cullumbine suggests that with short moderate exercise no significant effect is seen because the large reserve of the oxygen-carrying power of the blood is not strained. At the normal resting rate about 25% of the available oxygen is given to the tissues but during heavy exercise as much as 75% of the oxygen may be given up (30). With short severe exercise the subject becomes exhausted too fast for any changes in haemoglobin concentration to be noticeable. The oxygen debt is too large to be influenced significantly by small changes in the haemoglobin level.

Several investigators (4, 38, 58) reported significant correlations between the total amount of haemoglobin in the body and maximum oxygen uptake. Kjellberg et al. (39) reported a marked correlation (+.90) between the amount of haemoglobin and pulse rate during work at which the pulse reached a level of about 170 beats/minute.

The explanation as to why total haemoglobin correlates with performance and haemoglobin concentration does not is that the total amount of haemoglobin in the body is related to body size. In the case of a small girl and a large girl in the same physical condition, they may have similar haemoglobin concentration values. However, because of her body size the large girl will have a larger blood volume and haemoglobin volume and a higher physical work capacity value. Similarly Sjostrand (51) reports that during physical training both blood volume and haemoglobin volume increase so haemoglobin concentration remains constant. With training one can also expect work capacity to increase.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to investigate the effects of four stages of the menstrual cycle on physical work capacity 170. The subsidiary problems investigated the effects of four stages of the menstrual cycle on haemoglobin concentration, and the relationship between haemoglobin concentration and physical work capacity 170.

Twenty-five students enrolled in the physical education and recreation professional programs, University of Alberta, participated in the study. All subjects were free of any acknowledged menstrual disorders, had regular menstrual cycles approximately twenty-eight days in length, and were not taking oral contraceptives. All subjects were tested on the mid-day of each of the following four phases of the menstrual cycle: flow phase -- days of actual menstruation (day 1 - 4), postflow phase -- nine days immediately following the last day of menstruation (day 5 - 13), midflow phase -- eight days immediately preceding the preflow phase (day 14 - 21), preflow phase -- eight days immediately preceding the onset of menstruation (day 22 - 28). At each test session the subjects were measured on weight, haemoglobin concentration, and physical work capacity 170 by means of the Sjostrand Test. All determinations were completed within a six-week period and each subject was tested over one complete menstrual cycle.

The test data were analyzed by a one-way analysis of variance procedure with repeated measures to determine the effects of four phases

of the menstrual cycle on PWC_{170}. The relationship between PWC_{170} and haemoglobin concentration was estimated by using the Pearson product-moment correlation as described by Ferguson (24).

Conclusions

Within the limitations of this study, the following conclusions were made:

1. There were no significant differences in physical work capacity 170 values measured during four different phases of the menstrual cycle.
2. There was no significant difference in PWC_{170}/haemoglobin concentration measured during four different phases of the menstrual cycle.
3. There was no significant relationship between haemoglobin concentration and physical work capacity during any phase of the menstrual cycle.

General Conclusion

On the basis of this study, it may be concluded that physical work capacity did not differ significantly during the four phases of the menstrual cycle.

Recommendations

Studies concerning the effects of the menstrual cycle on performance should take into account relevant psychological changes throughout the cycle that may affect performance.

A further breakdown of the menstrual cycle might result in a more accurate determination of its effect on athletic performance.

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APPENDICES

APPENDIX A

SAMPLE CALCULATION SHEETS

DATA SCORE SHEET

Subject No:__________ Date:__________

Name:__________________________ Age:__________ Year:__________

Menstrual Cycle Phase:__________ Height:__________ Weight:__________

LEVEL 1	LEVEL 2	LEVEL 3
KP.__________	KP.__________	KP.__________
Revs.__________	Revs.__________	Revs.__________
Heart Rate	Heart Rate	Heart Rate
Min. 1 _______	Min. 5 _______	Min. 9 _______
2 _______	6 _______	10 _______
3 _______	7 _______	11 _______
4 _______	8 _______	12 _______
Steady State _______	Steady State _______	Steady State _______

Hb Concentration __________ x .071 = __________

Room Temperature:_____________ PWC_{170} _____________

Barometric Pressure:_____________

Comments:

APPENDIX B

RAW SCORES

RAW SCORES -- WEIGHT (KG.) DURING FOUR PHASES OF THE MENSTRUAL CYCLE

SUBJECT NUMBER	FLOW	POSTFLOW	MIDFLOW	PREFLOW
1	53.75	51.71	52.84	52.84
2	65.77	63.96	64.86	65.77
3	61.69	59.88	61.24	60.56
4	64.86	65.32	65.77	66.23
5	52.39	52.16	53.75	53.52
6	58.29	58.06	58.74	58.29
7	62.60	61.69	61.69	63.05
8	49.90	49.44	49.67	49.22
9	48.77	48.54	48.99	49.22
10	67.36	66.23	65.55	65.77
11	58.06	58.51	55.79	56.25
12	58.74	58.74	58.74	58.29
13	56.25	56.70	56.25	56.70
14	63.96	63.73	63.96	63.73
15	61.24	60.78	61.46	60.33
16	67.36	66.91	68.04	67.13
17	54.89	54.89	53.98	54.89
18	48.76	48.99	49.44	49.90
19	64.86	63.96	64.86	65.10
20	84.60	84.14	82.56	84.14
21	55.57	55.57	56.02	55.79
22	68.27	67.81	66.68	68.95
23	53.98	53.52	53.07	52.62
24	57.38	58.29	57.38	56.47
25	57.38	58.51	58.74	58.51

RAW SCORES -- HAEMOGLOBIN CONCENTRATION (GM./100 ML. BLOOD)
DURING FOUR PHASES OF THE MENSTRUAL CYCLE

SUBJECT NUMBER	FLOW	POSTFLOW	MIDFLOW	PREFLOW
1	12.96	13.70	14.13	14.48
2	13.92	14.16	13.77	13.36
3	12.43	13.60	11.86	13.53
4	13.77	13.67	13.63	14.13
5	12.99	13.64	14.41	13.03
6	13.88	14.48	14.31	14.20
7	13.14	14.20	13.92	13.77
8	12.64	13.28	13.38	13.70
9	13.70	13.06	13.14	13.81
10	13.74	13.31	12.81	13.70
11	13.92	14.34	13.35	13.88
12	14.16	14.20	13.81	13.14
13	14.84	14.91	14.48	14.56
14	13.85	13.92	13.92	13.56
15	13.56	12.99	13.70	13.03
16	13.88	13.10	14.48	12.99
17	13.60	14.48	12.78	13.60
18	13.70	13.06	13.28	13.63
19	13.99	15.05	13.99	14.66
20	14.09	14.16	13.42	13.35
21	13.35	13.10	14.56	13.38
22	12.89	13.95	13.35	14.24
23	13.42	12.99	12.78	13.03
24	12.57	13.35	13.21	14.27
25	13.56	13.56	13.92	14.24

RAW SCORES -- SJOSTRAND PWC_{170} TEST -- FLOW PHASE

SUBJECT	HR1	HR2	HR3	KPM1	KPM2	KPM3	PWC170
1	109	143	170	300	600	750	765
2	106	136	161	300	600	750	829
3	120	143	161	300	450	600	706
4	104	130	150	300	600	750	945
5	124	150	170	300	450	600	624
6	120	141	167	300	450	600	631
7	107	134	150	300	600	750	967
8	121	141	173	300	450	600	598
9	118	145	167	300	450	600	649
10	97	132	158	300	600	750	855
11	113	148	170	300	600	750	746
12	112	147	164	300	600	750	783
13	124	148	173	300	450	600	582
14	118	145	164	300	450	600	630
15	106	142	161	300	600	750	826
16	99	129	154	300	600	750	886
17	107	142	166	300	600	750	800
18	113	146	170	300	600	750	758
19	119	134	155	300	450	750	894
20	100	124	155	300	600	900	1095
21	118	136	155	300	450	600	716
22	103	137	150	300	600	750	939
23	113	145	161	300	600	750	861
24	131	158	184	300	450	600	528
25	114	126	170	300	450	750	757

RAW SCORES -- SJOSTRAND PWC_{170} TEST -- POSTFLOW PHASE

SUBJECT	HR1	HR2	HR3	KPM1	KPM2	KPM3	PWC170
1	120	141	164	300	450	600	641
2	109	150	173	300	600	750	721
3	130	154	170	300	450	600	605
4	97	121	153	300	600	900	1024
5	138	161	173	300	450	600	570
6	111	161	187	300	600	750	650
7	110	137	153	300	600	750	981
8	122	148	173	300	450	600	578
9	99	154	180	300	600	750	726
10	117	146	170	300	450	600	669
11	108	147	173	300	600	750	766
12	126	148	158	300	450	600	727
13	119	137	161	300	450	600	646
14	98	139	175	300	600	750	676
15	102	134	167	300	600	750	790
16	104	120	148	300	450	750	972
17	100	143	167	300	600	750	789
18	103	141	170	300	600	750	763
19	121	139	155	300	450	600	729
20	100	126	153	300	600	900	1071
21	105	146	167	300	600	750	773
22	100	131	148	300	600	750	960
23	112	135	167	300	450	750	738
24	127	158	184	300	450	600	530
25	101	140	164	300	600	750	801

RAW SCORES -- SJOSTRAND PWC_{170} TEST -- MIDFLOW PHASE

SUBJECT	HR1	HR2	HR3	KPM1	KPM2	KPM3	PWC170
1	90	121	155	150	300	600	683
2	118	131	153	300	450	750	912
3	125	147	167	300	450	600	658
4	107	130	150	300	600	750	981
5	130	148	170	300	450	600	602
6	116	148	173	300	450	600	577
7	96	121	150	300	600	900	1086
8	130	142	161	300	450	600	707
9	104	155	176	300	600	750	744
10	97	145	164	300	600	750	801
11	107	128	164	300	450	750	780
12	116	134	161	300	450	600	676
13	111	144	170	300	600	750	727
14	104	133	170	300	600	750	779
15	110	128	145	300	450	600	825
16	111	131	164	300	600	900	1001
17	124	137	158	300	450	600	748
18	109	148	173	300	600	750	600
19	124	134	161	300	450	750	831
20	108	131	161	300	600	900	990
21	102	134	160	300	600	750	851
22	92	102	136	300	450	750	1070
23	114	130	150	300	450	600	770
24	129	161	184	300	450	600	531
25	111	130	148	300	450	600	791

RAW SCORES -- SJOSTRAND PWC_{170} TEST -- PREFLOW PHASE

SUBJECT	HR1	HR2	HR3	KPM1	KPM2	KPM3	PWC170
1	115	134	170	300	450	750	748
2	111	142	161	300	600	750	809
3	126	151	173	300	450	600	613
4	106	132	161	300	600	900	932
5	133	152	173	300	450	600	586
6	121	149	170	300	450	600	593
7	113	143	161	300	600	750	825
8	127	152	170	300	450	600	536
9	131	147	173	300	450	600	633
10	103	138	161	300	600	750	801
11	103	149	176	300	600	750	710
12	115	141	161	300	450	600	651
13	127	131	158	300	450	600	705
14	127	152	170	300	450	600	590
15	106	150	167	300	600	750	760
16	108	136	155	300	600	750	892
17	95	132	164	300	600	750	801
18	108	142	170	300	600	750	751
19	107	132	160	300	600	750	845
20	106	137	152	300	600	750	960
21	100	147	173	300	600	750	770
22	111	135	153	300	600	750	951
23	110	150	176	300	600	750	719
24	118	178	195	300	600	750	604
25	112	129	150	300	450	600	721